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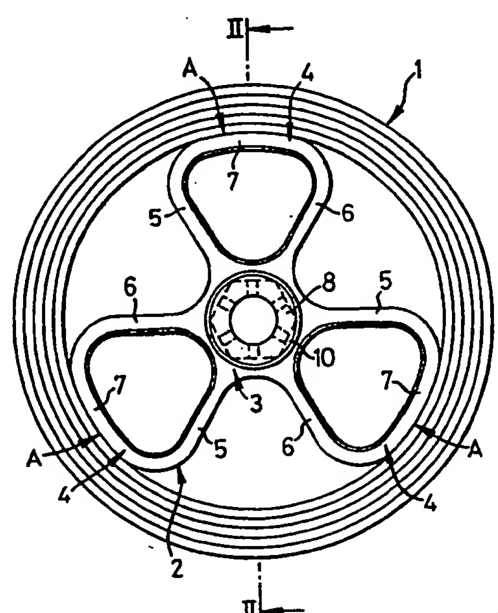
(54) **Energy storage flywheels.**

(57) An energy storage flywheel comprises a hub (3) having a plurality of spokes (4) and a rim (1) mounted on the spokes (4). The rim (1) remains substantially circular and substantially concentric with the hub (3) at all times. The spokes (4) are geometrically elastically deformable such that a force applied to the outer surfaces of the spokes and acting towards the centre of the hub (3) elastically deforms the spokes (4) thereby reducing their radial length. The spokes (4) which suitably are hoop shaped have a radial length, when not deformed, which is greater than the inner radius of the rim (1). The rim, hub and spokes are preferably manufactured from fibre composite materials. The flywheel is suitable for storing kinetic energy in motor vehicles.



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required to store relatively large amounts of energy. This is because the high density of metals gives rise to high levels of stress which can exceed the tensile strength of the metal. Preferably the material of construction has a lower density than metal but is at least equally strong. Suitable materials are fibre composite materials.

It is known that mass located towards the outer radius of a flywheel contributes more to the energy storage than mass located towards the centre of the flywheel. Thus a suitable flywheel construction is known to be one comprising a hub having a plurality of spokes and a rim mounted on the spokes so that it is substantially concentric with the hub, the rim being preferably made of a filament material wound in a matrix material

The construction of such a flywheel from fibre composite materials presents certain difficulties. Energy storage flywheels, particularly those flywheels constructed of low density materials, are required to operate at very high rotational speeds in order to obtain high energy densities. The centrifugal forces acting on a flywheel rotating at high speed result in a certain amount of growth in the radial direction. This means that the forces, which increase with increasing radial distance from the centre of rotation, tend to cause the rim to separate from the spokes.

One method of overcoming this problem is disclosed in British Patent Number 1534 393 which relates to a flywheel having a multi-layered rim which rim has a non-circular configuration when the flywheel is at rest and has a substantially circular configuration when the flywheel is rotating at a predetermined speed. The flywheel comprises a spider having a hub and a plurality of spokes extending from the hub, each spoke having the same radial dimension to its outermost point, and a rim comprising a plurality of annular substantially concentric layers, the innermost layer having an average inner radius which is less than the radial dimension of the spokes. The rim is mounted on the spokes so that when the flywheel is at rest, the rim has a non-circular configuration. As the speed of the flywheel increases, the average radii of the layers of the rim increase and the rim becomes substantially circular, but remains in contact with the spokes.

shaped so that they are elastically deformable and so they will tend to return to their undeformed shape when the applied force is removed. However, the rim prevents the spokes returning to their undeformed shape because its inner radius is less than the radial length of the undeformed spokes.

The present invention will be described with reference to the accompanying drawings Figures 1 to 4.

Figure 1 is an end elevation of a flywheel according to the present invention.

Figure 2 is a sectional view of the flywheel taken along the line II-II of Figure 1.

Figure 3 is a sectional side elevation of part of a flywheel, on a greater scale than Figures 1 and 2, showing a mechanical interlock between the spoke and the rim.

Figure 4 is an end elevation of a second embodiment of a flywheel according to the present invention.

Figures 1 and 2 illustrate a flywheel according to the present invention comprising a rim 1 and a spider 2. The spider, comprises a hub 3 having three spokes 4. Each of the spokes 4, as shown in Figure 1, is in the form of a loop. Each spoke 4 comprises two elongate members, hereinafter referred to as arms, 5 and 6, attached at one end to the hub 3 and extending divergently therefrom, the ends of each pair of arms 5 and 6 distant from the hub 3 being joined by a third, curved section 7 to form a loop. The outer curve A of the curved section 7 is an arc of a circle having a centre midway between the two arms 5 and 6 and having a radius less than the inner radius of the rim 1.

Preferably each spoke 4 is symmetrical about a straight line passing through the centre of the hub 3 and the spokes 4 are equally distributed about the hub 3.

The hub 3, arms 5 and 6 and curved sections 7 are preferably integrally formed. The shape, dimensions and materials of construction are selected to give a spider having spokes 4 which are deformable so that their radial length may be varied between predetermined limits. A force applied to the outer surface A of the curved

being elastically deformed. The curves of the curved section 7 are selected so that the outer curve A of each spoke 4 provides a good contact surface between the spoke and the rim 1 at all operating speeds and the curves between the curved section 7 and the arms 5 and 6 are selected so that a force applied to the outer curve A in the direction of the hub can be transmitted to the arms 5 and 6, causing them to diverge, without over-stressing or causing fatigue in any part of the structure. Preferably the arms and curved sections are of the same uniform thickness.

The radial length of the spokes 4, before deformation, is selected having regard to the materials of construction and the overall dimensions and operating conditions of the flywheel as a whole. The radius of the inner surface of the rim 1 of the flywheel increases as the rotational speed of the flywheel increases. The radial length of the spokes 4 will also tend to increase due to the centrifugal forces acting on the material of construction of the spider 2. However, the increase in the radial length of the spokes is restrained by the rim. The deformation of the spokes introduced on assembling the flywheel is such that a good contact is maintained between the spokes and the rim without unduly stressing the spokes or the rim. By deforming the spokes on assembly, the spokes are prestressed. As the radius of the rim increases, the stresses arising in the spokes due to the centrifugal forces are opposed by the stresses introduced into the spokes during assembly. The net stresses in the spokes are therefore less than they would have been if the spokes had not been prestressed. The dimensions of the spider are therefore selected so that when the flywheel is rotating at its maximum operating speed the radial length of the spokes 4 is at least equal to the radius of the inner surface of the rim 1.

The rim is substantially circular in cross-section and preferably comprises a plurality of layers. However a rim having a single layer may in some cases be used. The rim 1 shown in Figures 1 and 2 has five layers 11 to 15. The rim I is preferably constructed from fibres wound circumferentially and bonded in a suitable matrix material. Suitable materials include carbon, aramid and glass fibres in epoxy

Thus the radius of each layer of the rim increases. As the inner radius of the innermost layer 15 increases, the radial length of the spokes increases due to the centrifugal forces acting on the material of construction of the spider 2. This increase in the radial length of the spokes together with the deformation of the spokes continues to urge the curved section of the spokes against the inner surface of the rim. Thus the rim 1 and spokes 4 remain in contact as the speed of the flywheel increases.

Since the spokes are preferably less stiff than the rim, the forces acting on the spokes to urge them against the inner surface of the rim are not sufficient to substantially deform the rim which therefore remains substantially circular.

In order to provide a safety margin the undeformed radial length of the spokes 4 may be greater than the radius of the inner surface of the innermost layer 15 when the flywheel is operating at its maximum operating speed. Suitably, the spider is designed so that the undeformed radial length of the spokes 4 is greater than the radius of the inner surface of the innermost layer of the flywheel when the flywheel is rotating at a speed exceeding 150% of the maximum designed operating speed of the flywheel.

The spider 2 of a flywheel according to the present invention is not attached to the rim 1 by means of a mechanical fastener because such means of attachment may result in undesirable stress concentrations or a significant decrease in the performance of the flywheel. The spokes 4 remain in contact with the rim 1 by virtue of the deformation of the spokes which urges the curved sections 7 against the inner surface of the rim 1 and by the relative radial expansions of the rim and spokes. However, a force, other than a force acting in a radial direction, which is applied to a flywheel of the type shown in Figures 1 and 2, may cause the spider 2 to slip on the inner surface of the rim. Displacement of the spider with respect to the rim could cause the flywheel to become unbalanced.

Preferably therefore a mechanical interlock is provided between the rim 1 and the spokes 4 of the spider 2. The mechanical interlock should restrict axial movement of the spokes with respect to the rim and keep the spider 2 and rim 1 in the same plane whilst not interfering with the radial movement of the rim and spokes.

Figure 4 shows a second embodiment of the invention in which the spider 2 comprises a hub 3 having two spokes 4. The maximum number of spokes 4 which the hub 3 may have is determined by the amount of deformation required; there must be sufficient distance between the spokes to accommodate the deformation. Preferably, the same amount of deformation is applied to each spoke at any particular moment.

The invention is illustrated with reference to the following example.

Example

A flywheel according to the present invention was constructed from a cylindrical rim and a hub having three deformable spokes.

The rim had the following overall dimensions;

Outside diameter	150.0 mm
Inside diameter	120.0 mm
Axial length	30.0 mm

The rim comprised three concentric layers and was manufactured by the filament winding technique which is well known in the art of composite materials. The dimensions and properties of the layers were as follows;

Layer	I.D. (mm)	O.D. (mm)	Filament Material	Volume % of filament	Modulus of Elasticity of the fibres (GPa)
1	120	132	E glass	55	75
2	132	146	Aramid	50	125
3	146	150	Aramid	50	125

The matrix material was an epoxy resin supplied by Ciba Geigy. The resin comprised an unmodified Bisphenol A resin sold as MY 750 and a diaminodiphenylmethane sold as HT 972.

The radial expansion of the rim due to centrifugal forces at 60 000 rpm was expected to be of the order of 0.4 mm.

The spider comprising the hub having three spokes, was of the shape shown in Figures 1 and 2 and had the following major dimensions:-

Radial length of undeformed spokes	60.4 mm
Axial length	30.0 mm
Thickness of arms and curved section of the spokes	5.0 mm

Claims

1. A flywheel comprising a hub having a plurality of spokes and a rim positioned on the spokes is characterised in that the rim is substantially circular and substantially concentric with the hub at all times, and the spokes are shaped so that they are elastically deformable, such that a force applied to the outer surfaces of the spokes and acting towards the centre of the hub elastically deforms the spokes thereby reducing their radial length, the radial length of the undeformed spokes being greater than the inner radius of the rim.

2. A flywheel as claimed in claim 1 characterised in that the spokes are radially deformable in the plane of rotation of the flywheel.

3. A flywheel as claimed in either of claims 1 or 2 characterised in that the spokes are in the shape of continuous loops extending from the hub.

4. A flywheel as claimed in claim 3 characterised in that each spoke comprises two elongate members attached at one end to the hub and extending divergently therefrom, the ends of the two elongate members distant from the hub being connected by a third member to form a continuous loop.

5. A flywheel as claimed in claim 4 characterised in that the outer surface of the third member is curved and is an arc of a circle the centre of which is midway between the two elongate members and the radius of which is less than the radius of the inner surface of the rim.

6. A flywheel as claimed in any of claims 1 to 5 characterised in that the spokes and the hub are integrally formed.

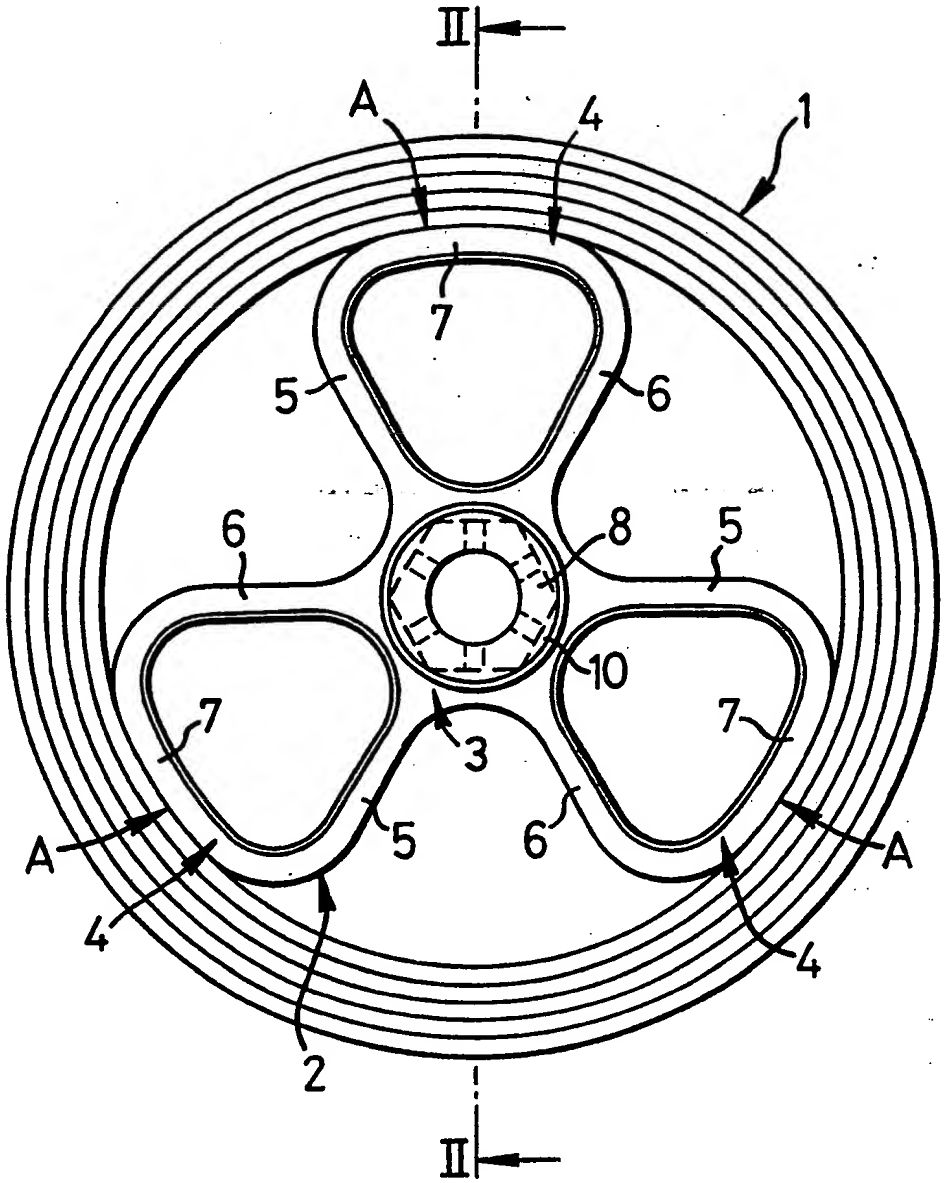

FIG.1

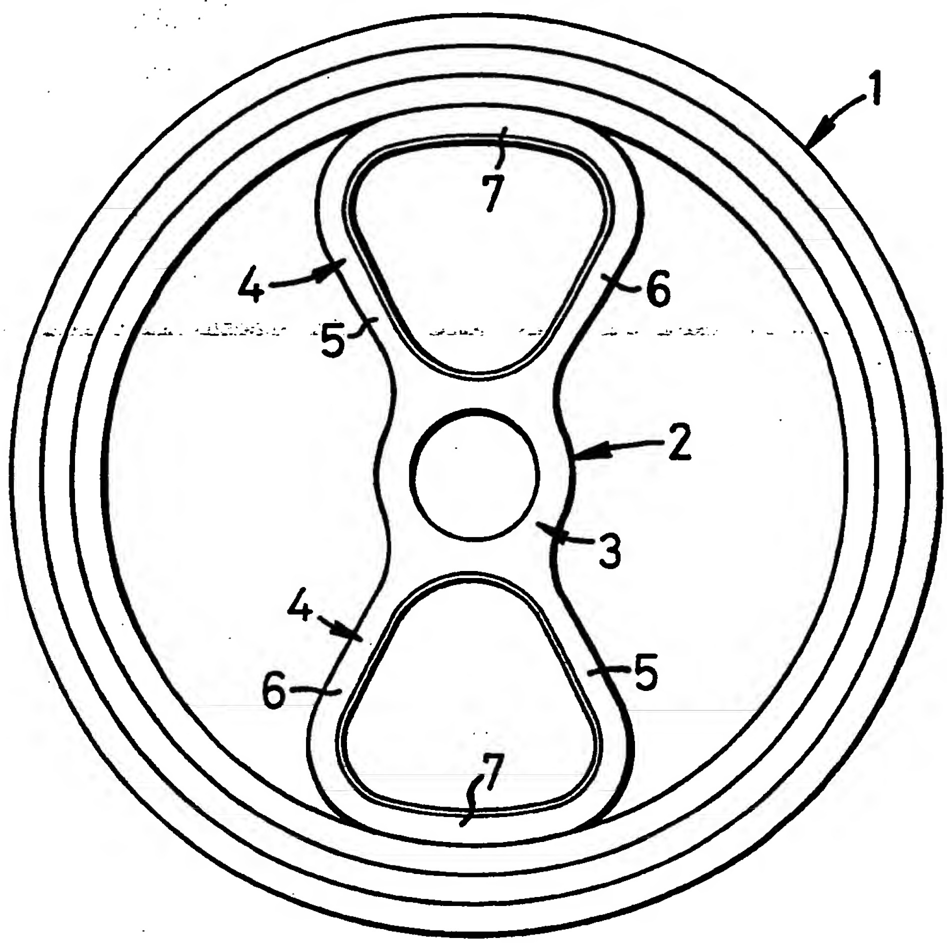

FIG.4